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Design and Development of a Pole Climbing Surveillance Robot

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ABSTRACT

The cost of installing, monitoring and servicing a fixed camera system can be high and not all areas are in need of constant surveying. The increase in crime in urban areas emphasizes the need for a more effective and efficient surveillance system, as a result could lead to fewer crimes. A temporary surveillance unit which is able to climb to gain an elevated view has great potential for both military and civilian application. This paper highlights how the patent pending climbing robotic system (PC-101) was developed to be used by London's Metropolitan Police Forensic Department for analysing outdoor crime scenes especially that related to car accidents. When cars are involved in accidents in the Metropolitan area, depending on the scale of the incident, the road generally has to be shut off to traffic if there are serious casualties. Elevated images are required for cases which may be taken to court, which then the images are then used as evidence, therefore regulations on the quality and perspectives of the image have to be met. By climbing a range of existing street furniture such as street lamp post, a temporary platform eliminates the use of larger special vehicle which struggles to get to the crime scene as well as cuts down the duration of the road closure. 98% of London street lamps in the Metropolitan area are constructed out of steel structures which make the use of magnetic wheels for locomotion an ideal solution to the climbing problem. Once remote controlled to the top of the lamp post, the PC-101 makes use of its actuated camera arm/gimbal to take the required shot, which can be seen on the ground control unit.

A surveillance tool of this sort can be used for many applications which include crowd/riot control, crime scene investigations, monitoring hostile environments and even the monitoring of nature within urban environments.

INTRODUCTION

In the UK surveillance has become a part of everyday living as there are more than 4.2 million cameras watching over the public. That is one camera for every 14 people, which makes Britain the most observed country in the world (BBC, 2006). Surveillance is a term used to monitor behavior, which in this case us humans, using various technological equipment. Surveillance technology has almost become a ubiquitous entity in our lives and can be found in airports, schools and retail stores. Surveillance devices fall under three categories, aural, visual or tracking. Cameras are the most common in the visual group. They can be seen in various public domains, such as banks, supermarkets and petrol stations and it is the best type of surveillance as it can provide an immediate and obvious indication of what is going on.

Combining surveillance equipment with robotics is not a new idea as it has been a popular collaboration for many years and is seen used by militaries around the world. Cameras combined with robotic systems can conduct challenging tasks which humans cannot or will not do. They perform the three D's; the dangerous, dull and dirty tasks (Singer, 2009).

Applications for mobile robot in high places such as inspection, surveillance and maintenance are dangerous and have being predominantly conducted by humans. Because of this, researchers from around the world have been developing climbing robots which can potentially replace the human risk factor (Choi, et al., 2004; Hirose, et al., 1991; Kim, et al., 2008; Wang, et al., 1999; Zhu, et al., 2002).

I. THE NEED FOR A CLIMBING SURVEILLANCE UNIT

Crime scenes which London's Metropolitan Police Forensics Department deals with are generally photographed depending on the severity of the crime scene itself. The images which are taken have to meet certain criteria's such as quality, perspective and size in order to be accepted as evidence in court. When dealing with crime scenes that are on a larger scale such as a car incident, the images which are taken need to capture the whole scene. There are a total of 2,500 deaths a year on the roads of Britain and capturing an image of the whole scene is only achievable if the camera point of view is elevated (Department for Transport, 2009) As can be seen in Fig. 1 and Fig. 2, not all information about the scene can be captured at ground level.

The task of capturing elevated images is currently conducted using an expensive telescopic mast attached to a large vehicle. See Fig. 3. The size of the mast attached to the vehicle is adjusted once the vehicle arrives at the crime scene which takes two people approximately 20-30 minutes. The mast itself is capable of extending to 75 feet but is never taken to that height due to Police health and safety regulations. The cost of the mast is £20,000 excluding the camera equipment and vehicle. On top of these cost there are additions such as maintenance of the vehicle and mast. Once the camera is attached the mast is extended to the required height and a single image is taken. The mast has to then be retracted to check the images usability as the camera is not adjustable once the mast is extended. The mast vehicle can only be deployed in specific locations around the Metropolitan area, as deploying the mast in built up areas can be dangerous. The mast is also affected by harsh weather conditions which make the operation of the mast not viable. The quality of the images relies heavily on the stability of the mast during the capturing of the images as the mast tends to wobble. To get to the crime scene of a car incident with a large vehicle such as a van also has its implications. The roads leading up to the scene are generally blocked in order for the scene to be preserved of any contaminates which could affect the scene, as a result would delay the vehicle from reaching its destination. A road closure would also run up a cost of approximately £20,000 to £50,000 per hour depending on the location of the road and the frequency of that road use.

Fig. 1 Image of a crime scene at ground level.

Fig. 2 Elevated image of the same crime scene showing more detail of the area.

Fig. 3 Vehicle used by Metropolitan Police Force for capturing elevated images.

When interviewing the specialist in the Forensics Department, the question about the usability of the Police helicopter to take the required images from above was raised. The answers which highlight the cost and feasibility of a helicopter in dense urban environment made it impossible to use helicopters just to take an image. The usability of existing closed circuit television (CCTV) cameras highlight that the cameras are not always looking in the correct location (blind spots) and that requesting the correct images would take longer than using a mast (Bishop, 2009).

The need for a man portable robot which is capable of taking images from an elevated view became evident. It had to be able to perform by using existing street furniture to climb to the required height. By using existing street furniture to gain height, the need for a specialist vehicle would become redundant. The quicker the images are taken and the road is cleared, time and money would be saved.

II. System design

A. Mechanical Design

After analysing the urban landscape of the London Metropolitan area, the most common street furniture is street light columns. Buildings are also commonly found in the Metropolitan area, but not all of them are high enough to capture the required elevated view as well as the non uniform building materials which may complicated the design. Street lighting columns share common features which would bring simplicity to the design of the robotic system. In order to set a more detailed design specification, a full understand of the various street lighting columns that are available, have to be determined. Factors such as materials, dimensions and other properties had to be collected which would then outline the design constraints and capabilities of the system. In the UK, lighting columns are designed to react differently when impacted by a vehicles travelling at different speeds (Petitjean, 2005). Because of this design aspect, in a field study carried out in the spring of 2009, 98% of street lighting columns in the London Metropolitan area are made out of steel at S275Jxx and S355Jxx, which have different impact ratings. The remaining 2% are constructed out of a plastic

Fig. 4 Typical street lighting column in London's Met area.

composite, stainless steel or concrete. 38% of the lighting columns taper towards the top, 88% are circular in cross section with an average 155 mm diameter and with an average height of 8 m. Lamp post on main high streets have signs which display various information about the road usage, which restricts the platform to only use a single side of the column for climbing (Erbil, et al., 2009). See Fig. 4.

The size of the total package including the control unit and platform also had to be able to fit into a small flight case no bigger than 600 x 400 x 200 that the Police force currently utilises to carry other equipments. After a design generation session, with all the information about the climb structures and size restrictions, a two wheeled climbing platform was created. Each wheel housing 14 permanent magnets paired with high-torque low-RPM geared motor, the locomotion of the platform became possible. As can be seen in Fig. 5, the patented Pole Climber (PC-101) platform is capable of carrying a digital stills camera equipped with wireless transmission for control of shutter, to the top of the lighting column where the camera can be rotated around the column with an articulating arm. The PC-101 unit is able to traverse up the lighting column on a single side avoiding any obstacles, and once at the top it deploys the arm to aim the camera in the right location by panning and tilting. Because the platform has no control of steering, the arm is able to cover 360˚ from the centre of the column. The system weighs approximately 2.5 kg and is constructed out of Aluminium, Carbon Fibre and Plastic to maintain high level of robustness whilst keep the weight to a minimum.

Fig. 5 PC-101 attached to lighting column.

B. Wireless Control System

The control of the platform is achieved using an Xbee 2.4 GHz transceiver which communicates to the microcontroller and motor speed controllers to move up or down from a operation range of 30 m. From the handheld remote, independent control of the drive system, arm and camera can be selected. Whilst the system is in locomotion, the arm is in the retracted position which sets the weight of platform to be closer to the lighting column for stability. The articulation of the arm relies on high-torque metal geared servo motors. As can be seen in Fig. 6, the handheld controller also has a built in LCD screen which displays the images from the camera at a range of 100 m. This one controller is able to operate multiple platforms independently and can switch between the platforms with the flick of a switch. The control unit also has a CF memory card slot which the taken images can be stored on. The images are transmitted over a secure wireless connection as the nature of the images is sensitive.

Fig. 6 Ground Control Unit with joystick for arm articulation and system locomotion.

III. PROCESSES OF MANUFACTURE

The processes which were involved in the making of this prototype were not too complex which helped in keeping the costs down. All the machinery used in the making of PC-101 was available in-house, which accelerated the prototyping stage as none of the parts needed to be made externally. The wheels were turned down out of a solid extruded aluminium rod using a manual lathe, but can also be turned down on a computerised lathe if mass production is to be considered. From experience, the radial grooves on the outside of the wheel would be turned down first then the inside of the wheels would be hollowed out as the piece would be much more stable under high speeds. But the size of the wheels (100 mm diameter) and the thickness of the wheel walls really wouldn't make a difference. Once the wheels were hollowed out, the piece was then turned around to work on the central hub and radial grooves. See Fig 7. Once completed, the wheels were then clamped into a milling machine for the flattening of the 14 faces where the magnets will sit into.

Fig. 7 Turning down process.

The chassis compromises of three pieces which were made out of 4 mm aluminium using a water jet cutter. This machine precisely cut out the main chassis and the motor brackets in less than five minutes using high pressure water and garnet. All parts were then assembled to test the initial climbing capabilities. See Fig. 8.

The next stage of prototyping was to construct the hand held controller and add wireless control to the platform and test it. See Fig. 9. As can be seen in Fig. 10, the components from the hand held unit was then transferred into its own enclosure which is more robust. The final stage of prototyping was to program the whole system. See Fig. 11.

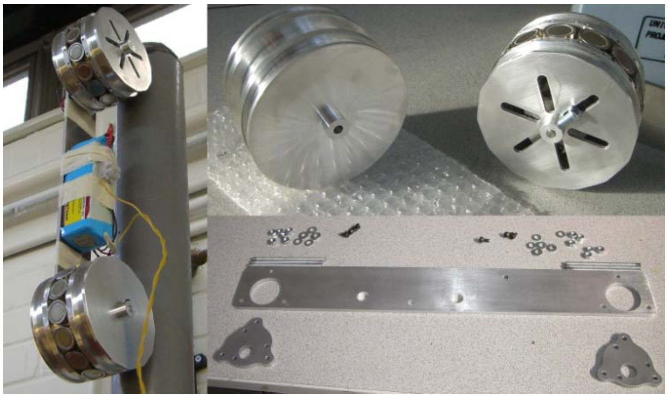

Fig. 8 Chassis assembled and first stage of testing.

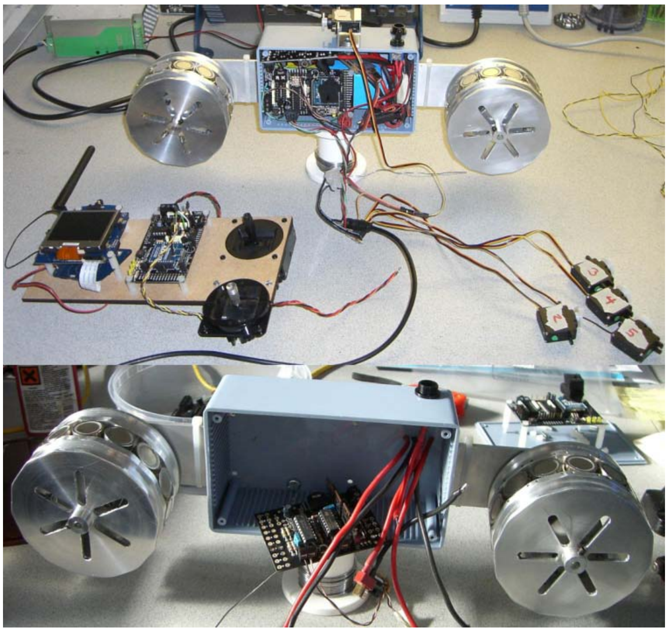

Fig. 9 Electronics added to main platform and handheld controller.

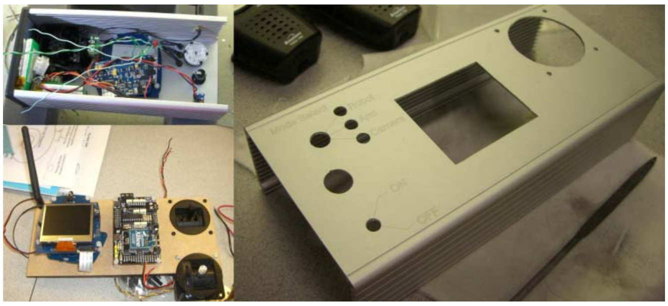

Fig. 10 Finishing off hand held controller.

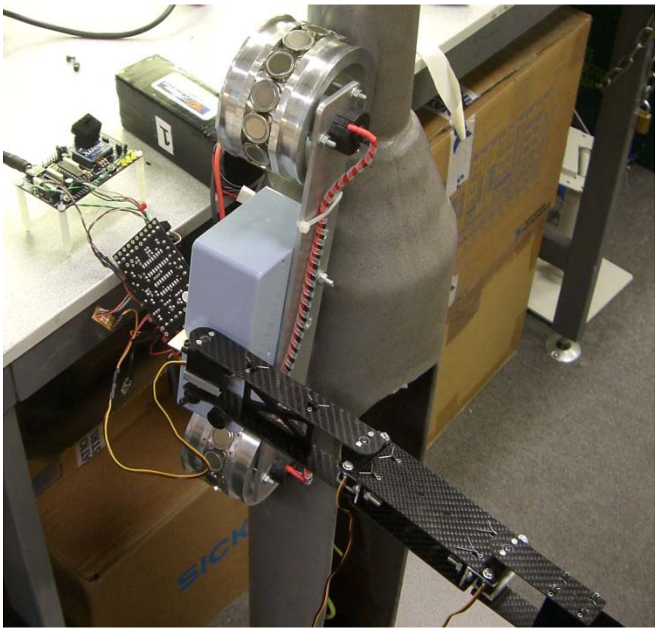

Fig. 11 Testing of the complete system on dummy lamp post.

The working ethos of this project was to test at every single stage possible; therefore eliminating any problems once the whole system was assembled. This is also a cost effective method, as any major problems can be resolved without getting too deep into the design process. The overall time scale from design to final working prototype took less than eight weeks.

IV. OPERATIONAL PRINCIPLE

As mentioned before, the platform employs two wheels with 14 permanent magnets placed 25.7˚ apart from the central drive axis. The motor driving the wheels are rated at 15.5 rpm at no load and 8.3 rpm at stall with maximum current draw of 0.3 A per motor @ 12 VDC. During normal operation, each motor has a current draw of 0.21 A which is at maximum efficiency of 30%. The logic behind selecting permanent magnets over electro magnets is the simple reason of using minimal power use. Using electro magnets also pose a danger of the system falling off the lighting column when battery levels have depleted.

Whilst still at the prototyping stage (1) and (2) equations were used to roughly work out the torque required to drive the system up the column. The radius of my wheel was 50 mm, so the force was 2.5 * 9.81 = 24.53 Nm. The torque worked out to be 24.53 * 0.05 = 1.23 Nm. So each motor would require 1.23 Nm/2 = 0.615 Nm. The McLennan 1809 motors with a gear ratio of 200:1 had a maximum torque of 1.167 Nm. So operations at 0.21 A the torque works out to be 0.611 Nm in real life tests. See Fig. 12.

$$\text{Force} = \text{Mass/Acceleration} \qquad (1)$$

$$\text{Torque} = \text{Force} * \text{Distance} \qquad (2)$$

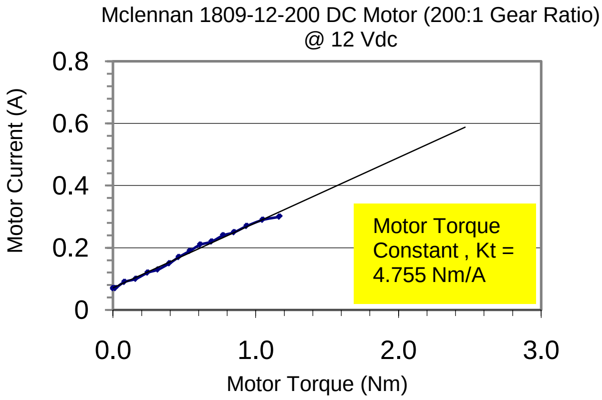

Fig. 12 PC-101 attached to lighting column.

Further testing was carried out to test the torque required to move the wheels when in contact with horizontal and vertical planes and metallic and non-metallic surfaces. Fig. 13 shows the different configurations which the wheel was put on and then weights added. The results highlight that the average torque of 0.58 Nm was required before the wheel started moving.

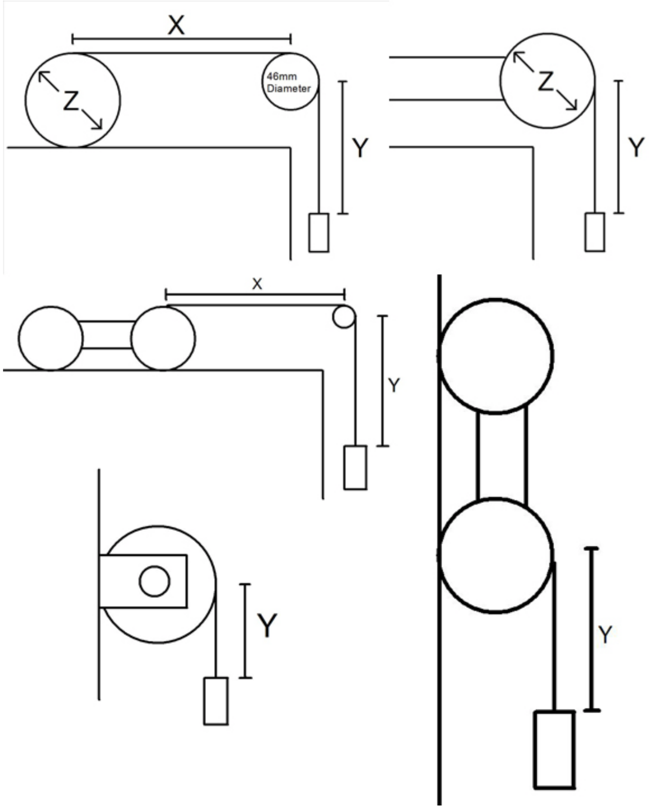

Fig. 13 PC-101 attached to lighting column.

The array of magnets on the wheel works in a way which there is always one magnet fully in contact with the surface. As the wheel rotates, the next magnet then attracts the wheel, therefore resulting in upwards motion. Fig. 14 shows how the two magnets surrounding the central magnet aids with the static hold force. Fig. 15 shows the different wheel configuration that was tested to see what the effects of the surrounding magnets would be on the overall holding force.

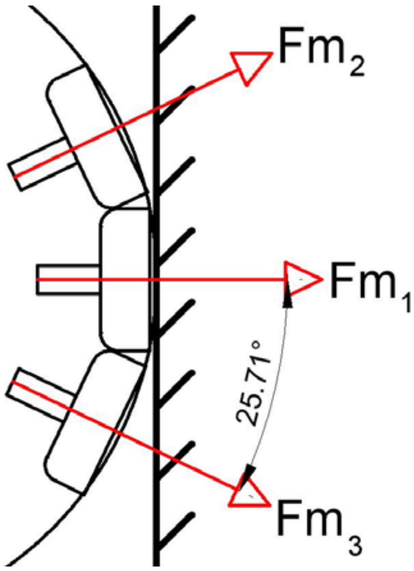

Fig. 14 Magnetic forces on flat vertical surface.

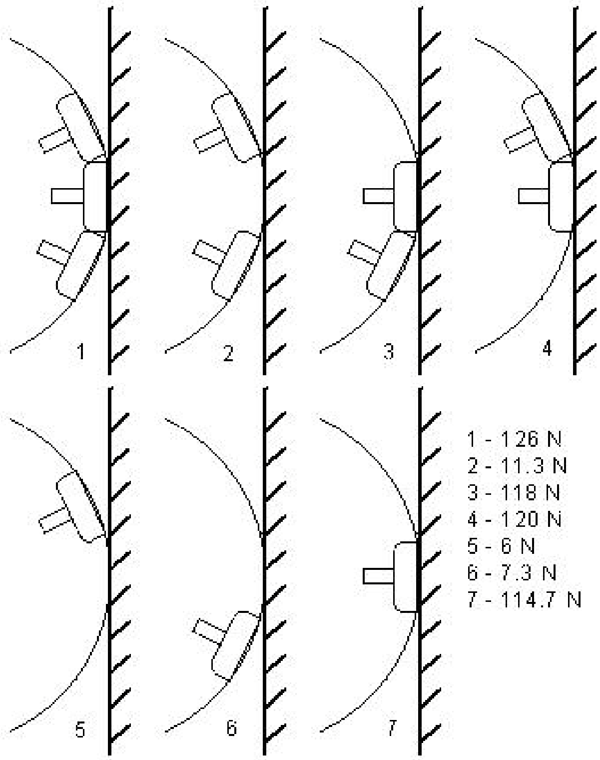

Fig. 15 PC-101 attached to lighting column.

With the use of a Hounsfield H20K-W material force testing machine, the force varied as magnets were added and taken away. Results from the 3rd and 4th configuration shows that a difference in forces differs from magnet to magnet. Because of this variation, each individual magnet would need to be tested. Preliminary results showed that changing the orientation of the magnet affects the hold forces. In light of these result each one was tested once in 4 orientations as shown in Fig. 16 with 0˚, 90˚, 180˚ and 270˚ pointing upwards.

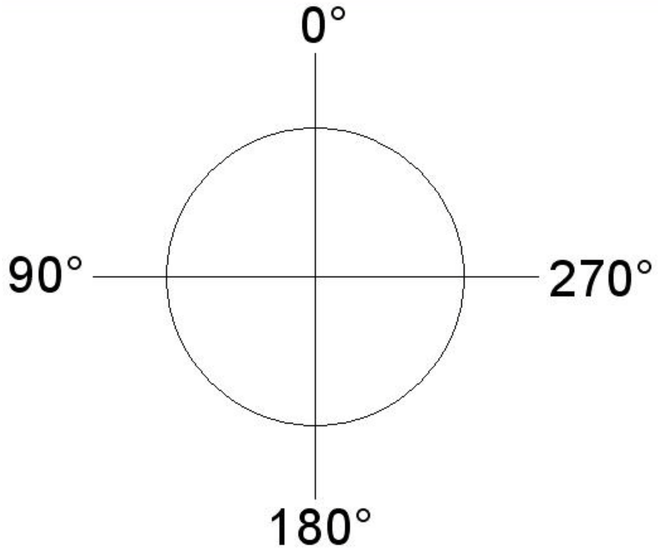

Fig. 16 Magnet 360˚ orientation.

The difference the orientation made to the force required to pull away from a metallic surface varied by an average of 10-20 N. Some varied much more, where others were consistent out of the 112 tests carried out.

V. Design Optimisations

Although PC-101 has met every requirement set by the Metropolitan Police Forensic Department, the system can still be improved to enhance its performance further. If a larger camera were to be added the system no longer is able to cope with the extra weight therefore begins to slide down the column. By keeping the same wheel and chassis configuration it may be possible to reduce the weight of certain components such as the wheels. Each wheel weighs approximately 600 grams and is constructed out of aluminium. This material can be substituted for an alternative material such as nylon as the design process will remain the same. The chassis which includes the motor plate, microcontrollers and battery can slightly be modified by swopping the battery for lower capacity battery. With the current configuration of the two wheels separated by a distance of 310 mm, the first wheel tries to negotiate a small obstacle which may be a protruding part of the column design, resulting in the platform falling off the column if the protrusion is greater than 15 mm. To overcome this problem, bringing the wheels closer together will aid in traversing over these protrusions.

VI. Conclusion & Future Work

The PC-101 platform is a fully functioning surveillance unit which is capable of climbing up street lighting columns to gain an elevated perspective of a targeted location. Compared to current systems used to gain the same desired elevation, PC-101 is much more efficient, cost effective and safer than the other methods. With further development, this system has great potential to be used in a day-to-day operation by local law enforcements for surveillance or any other groups, companies or authorities.

Acknowledgment

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